

Bench Measurements on the TEV-I Target Cooling System

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I. Introduction

The TEV-I target used for producing antiprotons during the 1987 - 1988 collider run was bombarded with $1.25 \text{ E}+12$ ppp every few seconds for several million pulses. After the target had been allowed to cool-down for 1.0 - 1.5 years, it was disassembled and inspected. Visual examination showed that the surfaces of the copper disks and copper cooling channels were covered with a charcoal-black deposit - indicating that beam heating had elevated the temperature of the target significantly. The target used during the most recent collider run (where typical Main Ring intensities were $1.75 \text{ E}+12$ ppp) will undoubtedly show similar, but more pronounced, features when it is disassembled. The maximum temperature which the target reached during these runs is unknown, because the target had not been appropriately instrumented during these runs.

A knowledge of the maximum temperature which the target attains is important for several reasons. At sufficiently high beam power bulk melting of the target will occur. At lower intensities, local melting along the beam axis, during a single pulse, is expected. The threshold of beam power at which either local or bulk melting begins depends upon the average ambient temperature of the target; which, in turn, depends upon the efficacy of the cooling system.

This note summarizes the results of measurements made on the existing cooling system using a fresh (i.e., unirradiated) target and a resistive heating source. Section II describes the experimental setup used for making the measurements; Sections II and III summarize the results obtained for the "cooling time constant" and "heating time constant" of the target, respectively. Section IV reviews the adequacy of the existing cooling system for future runs, and outlines how the bench measurements will be used to monitor the average ambient temperature of the operational target.

II. Cooling Rate Measurements

The schematic layout of the experimental setup used for the cooling rate measurements is shown in Figure 1. The resistive heating element shown in the figure was used to raise the target temperature to 250 degrees C., at which point the heating element was turned off and the air compressor was turned on and maintained at a uniform flow rate. The time constant for cooling the target was measured for 0, 2, and 4 SCFM, using the three thermocouples (TC1, TC2, TC3) shown in the figure.

Figures 2 and 3 display the cooling curves determined by thermocouples attached to the target (TC1) and in the exit air flow stream (TC3), respectively. The data from the remaining thermocouple, TC2, is not shown since it is identical to that of

TC1, i.e., the entire copper region of the target is cooled at a uniform rate by the air stream. Figures 2 and 3 show not only the raw temperature measurements but also curves which allow one to extract cooling time constants from the data. The curves are the results of the following three parameter regression analysis:

$$T(t) = A + B * \exp(-C * t)$$

As Figures 2-3 indicate the goodness-of-fit to this representation is excellent. The time constants obtained from the regression analysis are summarized in Table 1.

Tabel 1. Time Constants From Cooling Rate Measurements

Air Flow (SCFM)	Thermocouple on Taraget	Thermocouple in Exhaust Air Stream
2	0.63 hrs.	0.62 hrs.
4	0.41 hrs.	0.43 hrs.

As Table 1 shows, the time constant determined from measurements of the exhaust air stream temperature agrees quite well (better than 5 %) with that determined from measurements of the surface temperature of the target. This suggests that (with proper calibration) measurements of the exhaust air stream temperature taken after the AP-1 beam has been turned off (e.g., during a "shot") can be used to determine the maximum bulk temperature of the target during normal operation. Consequently, the thermocouple which measures the exhaust air stream temperature will be incorporated into the operational target module for future production runs. The availability of measurements of the air stream temperature will make it possible not only to monitor the target temperature but also to verify that the target cooling system is functioning properly.

In using the air stream temperature data in the manner proposed above two implicit assumptions are being made, viz., that the cooling time constant of the target is independent of the initial (maximum) temperature to which the target is heated and that the cooling time constant determined from the measurements of the exhaust air stream temperature is also independent of the maximum temperature to which the target has been heated. To test these assumptions the target was heated to 350 degrees C. and a second series of measurements were made. The results are shown in Figures 4-5. The regression analysis of this data indicates that the time constant determined from the target surface temperature data is independent of the initial temperature at the 3% level, while that of the air stream temperature is independent of the

initial temperature at the 7% level.

III. Target Heating Measurements

The target heating tests were a series of measurements of the asymptotic temperature rise of the target for fixed power input and constant flow rate of the cooling air. The power delivered by the resistive heating element was intended to simulate the beam power deposited in the target. Consequently, for these tests the entire target was wrapped in insulation to ensure that as much as possible of the joule heat was transferred to the target.

This experimental configuration is not, of course, a completely accurate simulation of the effect of beam heating. On the one hand, even with the target wrapped with insulation some of the input power is undoubtedly not transferred to the target - resulting in an underestimate of the maximum target temperature. On the other hand, the presence of a layer of insulation eliminates most of the radiative and convective cooling which ordinarily occurs at the surface of the target - which tends to overestimate the maximum target temperature.

Because of these deficiencies the heating measurements are not expected to provide results which accurately represent the effect of beam heating. Rather, they represent an estimation of the temperature rise of the target for a given input power.

Temperature measurements from the thermocouples mounted on the target and in the exhaust air stream are shown in Figures 6-7, respectively, for various input power levels and flow rates. The asymptotic temperatures were determined by a three parameter regression analysis with the same functional dependence as was used for the cooling time constant determinations, i. e.:

$$T(t) = A + B * \exp(- C * t)$$

The results of the fit are shown as the solid curves in Figures 6 - 7. In every case, the theoretical function used in the regression analysis is an excellent representation of the data. Using the results of the regression analysis, one can extract the asymptotic (bulk) temperature rise of the target as a function of input power and flow rate of the cooling air. The results are shown in Figure 8.

During the next collider run we anticipate running conditions of (roughly) $2.0 \text{ E}+12$ ppp at a 2.0 second repetition rate. Under these conditions the calculated beam power would be 200 watts. Using Figure 8 as a guide suggests that we should expect the asymptotic (bulk) temperature of the target to rise by as little as 50 degrees C. or by as much as 180 degrees C. depending upon the flow rate of the cooling air.

IV. Summary and Conclusions

Two thermocouples have been installed in the operational target module to measure the temperature of the exhaust air stream. The data of Section II provides calibration constants in that a measurement of the cooling rate of the exhaust air temperature can be used to determine the maximum target temperature as well as to verify the flow rate of the cooling air through the operational target.

The flow output of the existing air pump in the target vault has been measured using the same flow meter that was employed for the measurements described in Sections II and III. The measured flow rate at the top of the target module was 1.5 SCFM. In addition the exhaust port of the target stack was modified so that a flow meter could be used to measure the flow rate at the exhaust port of the target. With a flow rate of 1.5 SCFM into the top of the module, the flow rate at the exhaust port of the target was less than 0.5 SCFM - the lowest flow rate which could be measured with the available instrumentation. Most of the loss of flow appears to occur at the junction where the target attaches to the shaft that penetrates the target module. This is somewhat reasonable since this junction appears to be a standard mechanical junction without any provision for a gas seal. In order to fix this leak it may well be necessary to replace the entire shaft assembly that penetrates the target module - a non-trivial undertaking.

We conclude that:

1. The existing air leak in the target module cooling channel needs to be fixed, even if this requires the replacement of the entire shaft assembly. Until this is done, the data of Figure 8 suggests that the temperature rise of the target will approach 200 degrees C. The actual temperature rise will be measured during the immanent fixed target run using the newly installed thermocouples.
2. After the air leak is eliminated, the existing air pump should be replaced by a compressor that will drive 4 - 6 SCFM (or more) through the target. Such a flow rate would limit the temperature rise of the target to 50 degrees C. during the next collider run and to approximately 120 - 150 degrees C. after the upgrade.

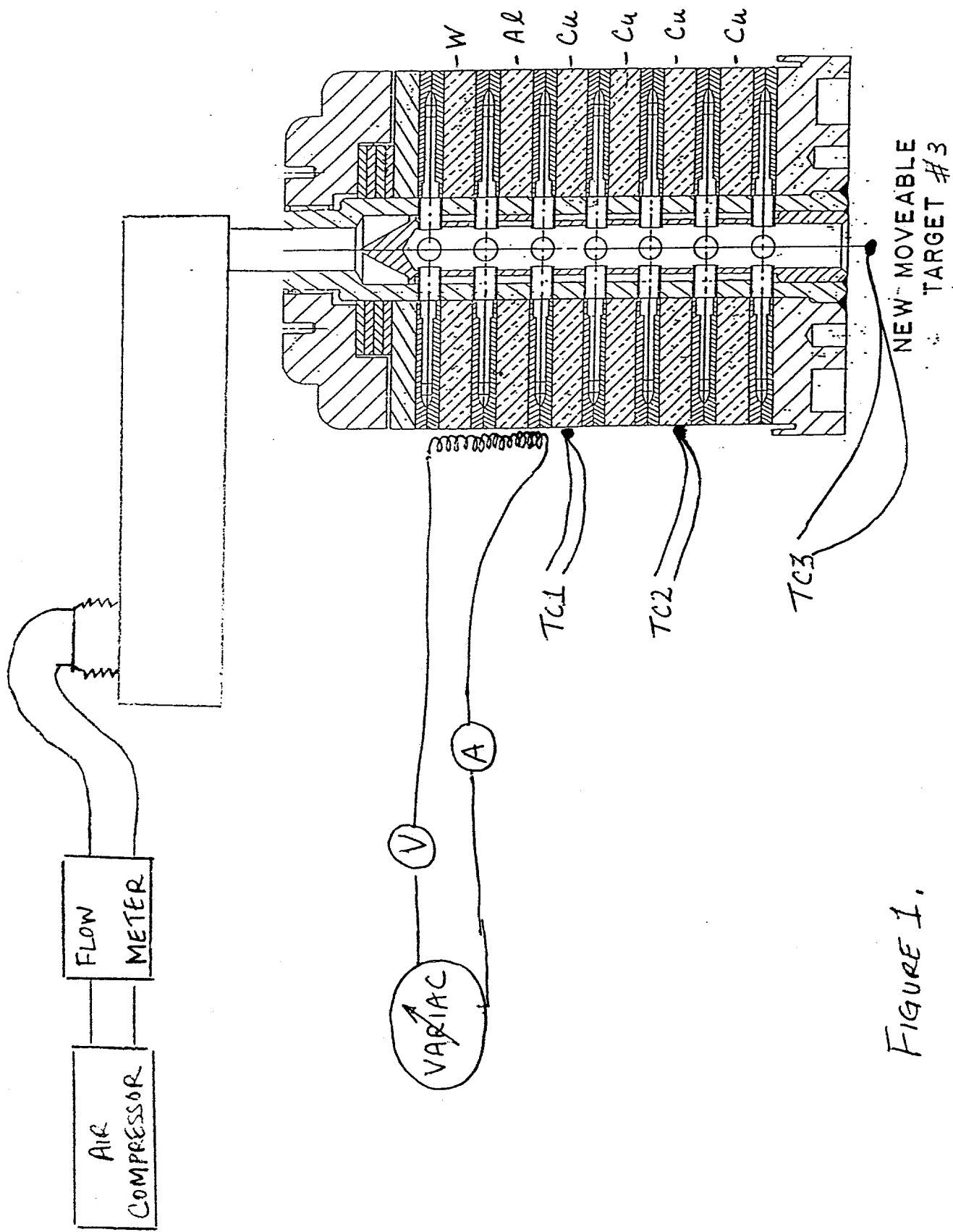


FIGURE 1.

FIGURE 2.
MEASUREMENT OF TARGET COOLING RATE

(TC ON TARGET)

AIR FLOW (SCFM)

0
2
4

FIT TO: $\alpha_1 + \alpha_2 e^{-(\alpha_3 t)}$
(OVER)

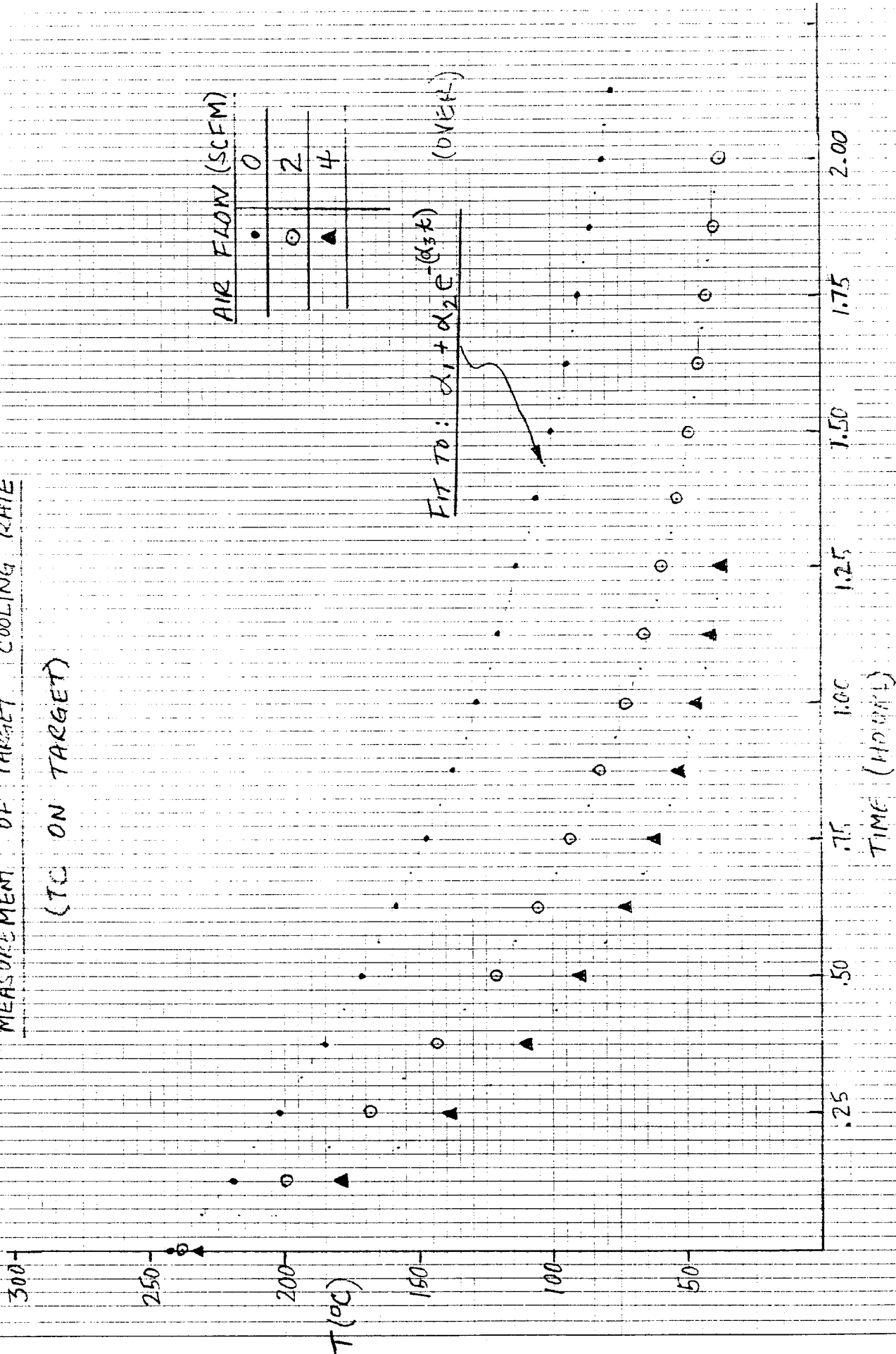


FIGURE 3
MEASUREMENT OF TARGET COOLING RATE
(TC IN AIRSTREAM)

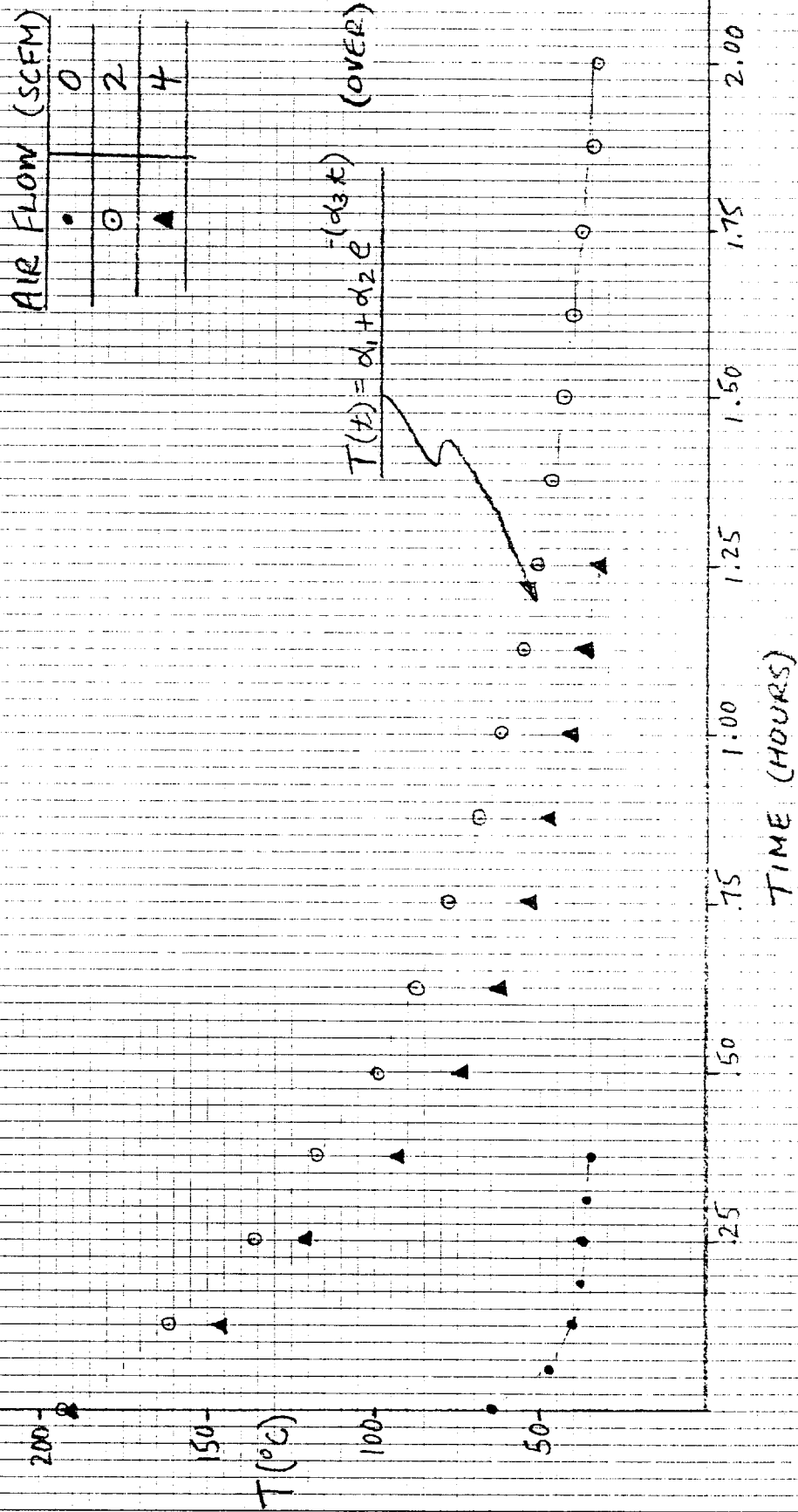


FIGURE 4.

MEASUREMENT OF TARGET COOLING RATE

(T/C ON TARGET)

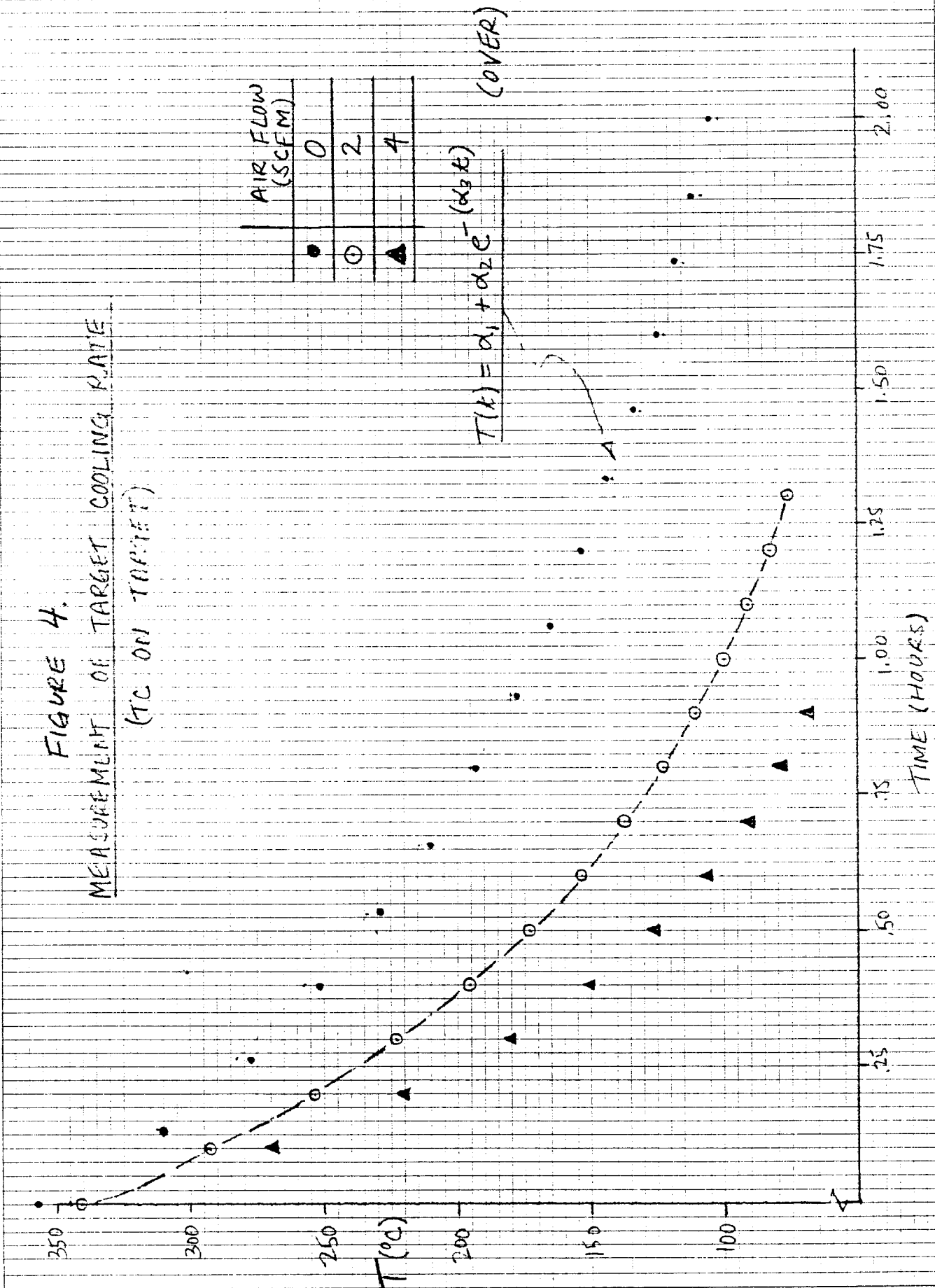


FIGURE 5.
MEASUREMENT OF TARGET COOLING RATE
(TC IN AIR STREAM)

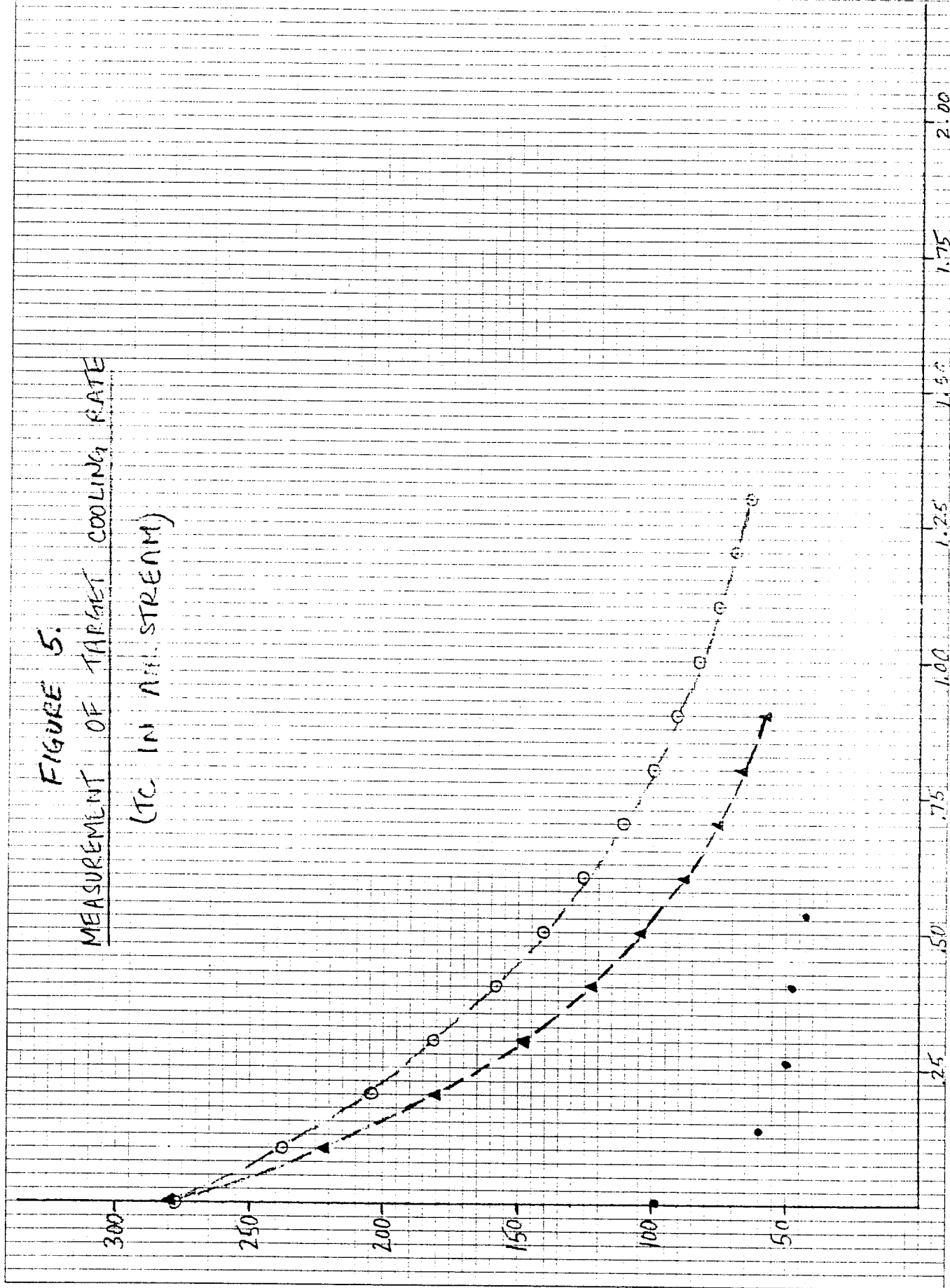
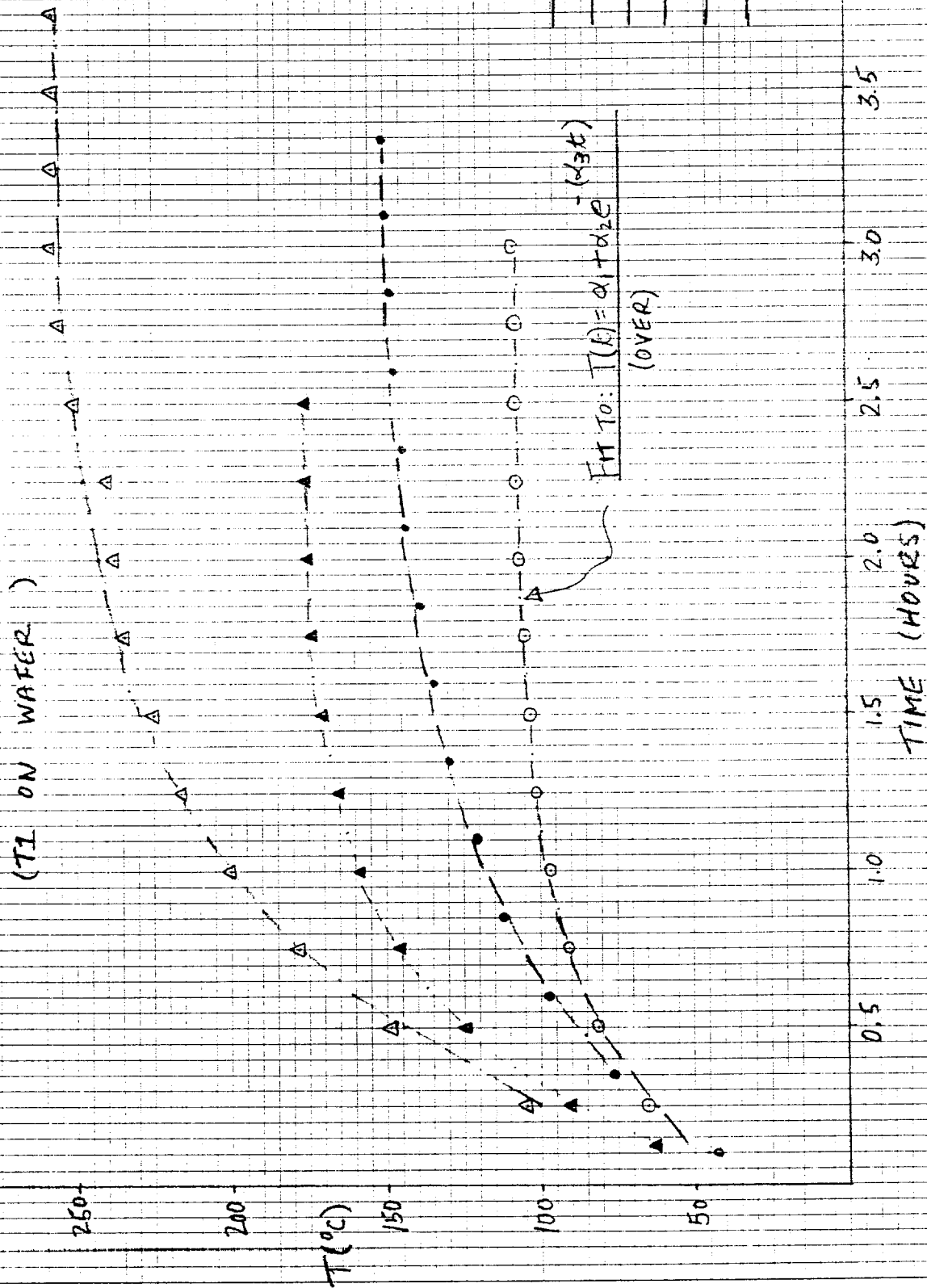
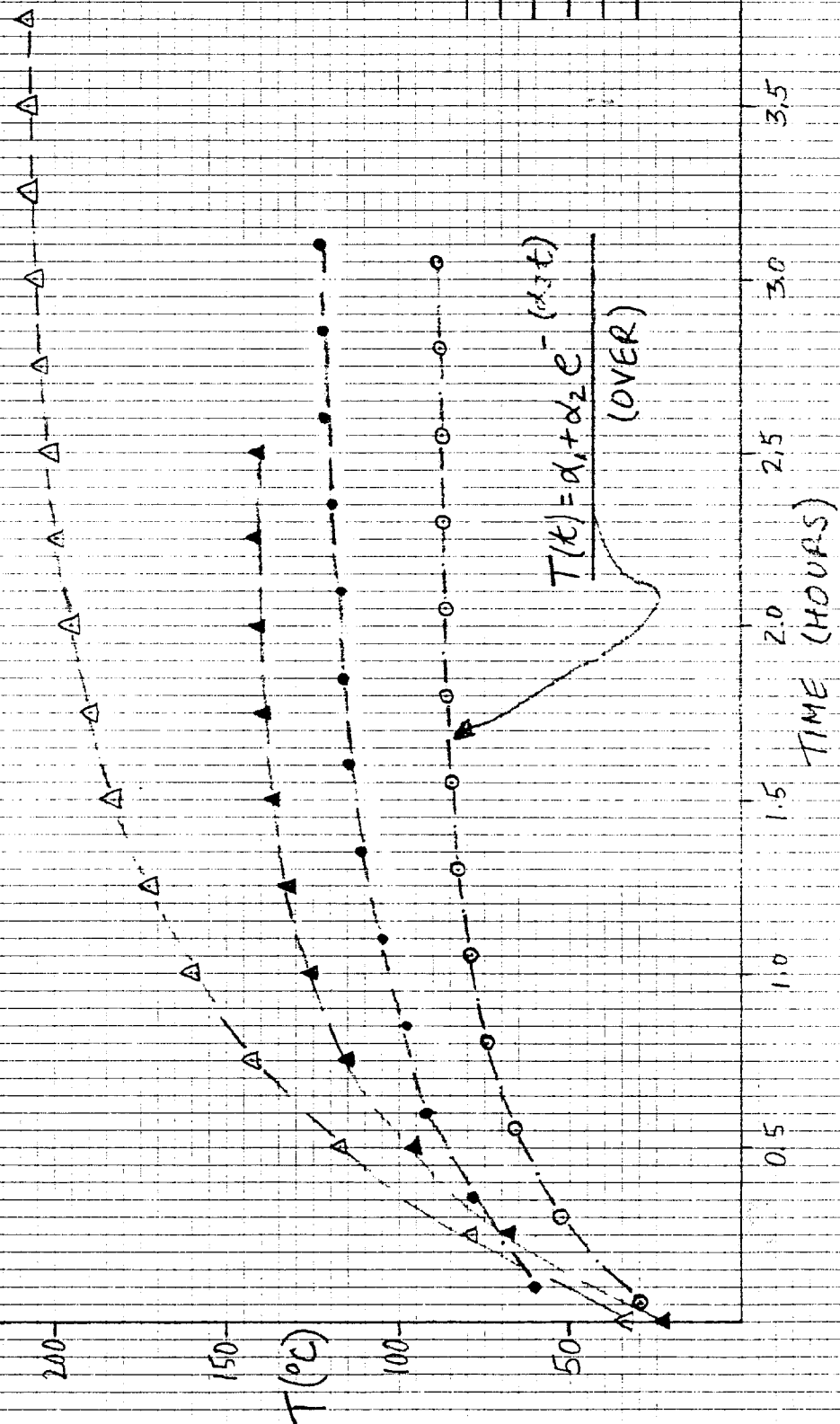


FIGURE 6.
MEASUREMENT OF TARGET HEATING RATE
(T1 ON WATER)



	AIR FLOW (SCFM)	POWER (WATT)
●	2	200
○	4	200
△	2	400
▲	4	400

FIGURE 7.
MEASUREMENT OF TARGET HEATING RATE
(TC IN AIRSTREAM)



	AIR FLOW (SCFM)	POWER (WATT)
●	2	200
○	4	200
△	2	400
▲	4	400

